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SIMULTANEOUS ACTIVATION OF BIMANUAL CONTROLS

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FOREWORD

This report was prepared by the Performance Requirements Section, Human Engineering Branch, Behavioral Sciences Laboratory, 6570th Aerospace Medical Research Laboratories. The work was done under Project No. 7184, "Human Performance in Advanced Systems," Task No. 718404, "Advanced Systems Human Engineering Design Criteria," with Dr. M.J. Warrick and Mr. Lester Turner serving as principal investigators. This research was conducted between February 1962 and August 1962. The authors wish to express their appreciation to Mr. N. Schwartz of the Behavioral Sciences Laboratory for his assistance in constructing the experimental apparatus. Figures 1 and 2 are reproduced herein with the permission of the Bell Aerospace Company.

ABSTRACT

The time interval between the release of a right-hand key and a left-hand key, when subjects were attempting to release them simultaneously, was measured to 0.1 millisecond. The mean interval of 20 subjects, 60 trials per subject without knowledge of results, was very close to zero (simultaneous). Approximately 94 percent of the intervals were within ±20 milliseconds of zero. The implications of the findings to the control of a personal space-propulsion unit are discussed.

PUBLICATION REVIEW

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SIMULTANEOUS ACTIVATION OF BIMANUAL CONTROLS

INTRODUCTION

In certain personal locomotion devices proposed for use in a space environment, an assembly of independently actuated, ON-OFF, fixed-thrust generators or rockets are mounted on each side of the man (figures 1 and 2). For a man using such a device to be able to move in a straight line without rotating, the force vectors at the two sides must be exactly equal, occur simultaneously, and result in a vector through the center of mass of the man-suit assembly. Even if the practical engineering problems of producing the proper force vectors can be solved, the system will not perform satisfactorily unless the man is capable of actuating the right- and left-hand controls simultaneously.

Figure 1. Zero-G Locomotion Belt Requiring Simultaneous Activation on Right and Left Sides

Figure 2. Close-Up of Thrust Actuator and Nozzles

To illustrate the potential seriousness of this apparently trivial human engineering problem, consider rotation about the longitudinal axis of the body. As an approximation, assume a space man-suit assembly to be a homogeneous, three-foot-diameter, 320-pound cylinder (figure 3). The inertia (I) of such a cylinder is given by the following formula:

$$I = \frac{1}{2} \underline{M} r^2$$

$$I = \frac{1}{2}\left(\frac{320}{32}\right) \times 1.5^2$$

$$= 5 \times 2.25$$

$$= 11.25 \text{ slugs}$$

where M = mass in slugs or weight/32 and r = radius.

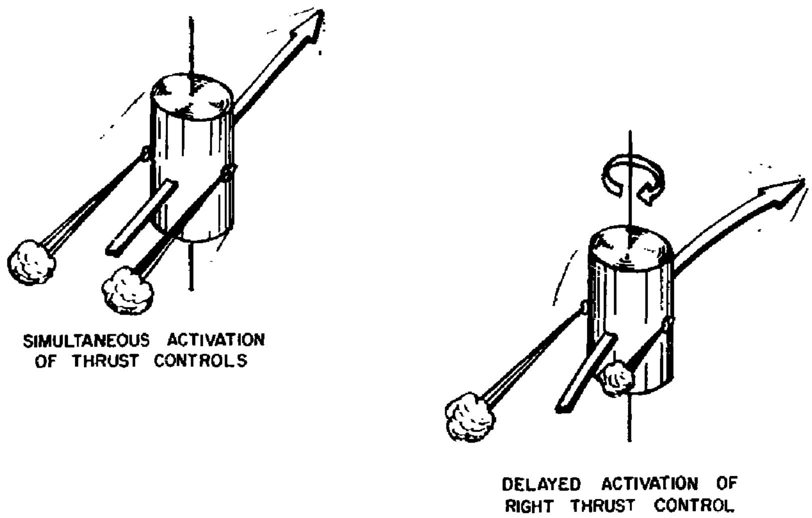

Figure 3. Activation of Thrust Controls

If a force of 20 pounds is applied tangentially, to one side of the cylinder, the angular acceleration (α) is:

$$\alpha = \frac{r}{I}$$

$$= \frac{20 \times 1.5}{11.25}$$

$$= 2.67 \text{ radians/sec}^2$$

Should the 20-pound force be applied for only 20 milliseconds the cylinder will attain a velocity of about 0.0534 radian per second or approximately 0.5 revolution per minute. In other words, if our *MAN IN SPACE* actuates one horizontal-thrust generator 0.02 second before the other, 1 minute later he will be facing the opposite direction. The same analysis applies to turning the thrust generators off. It is thus easy to visualize a confusing, energy-consuming, zigzag course of a space man as he attempts to move from one satellite to another.

The experiment reported herein was designed to determine man's ability to effect a simple control movement precisely simultaneously with his right and left hands.

METHOD

Apparatus

The experimental apparatus was quite simple. It consisted of three principal components: a subject's response panel, a control unit, and an interval timer (see figures 4 and 5). The control unit and the interval timer were hidden from the subject's view. Their operation did not provide the subject with auditory cues concerning his response.

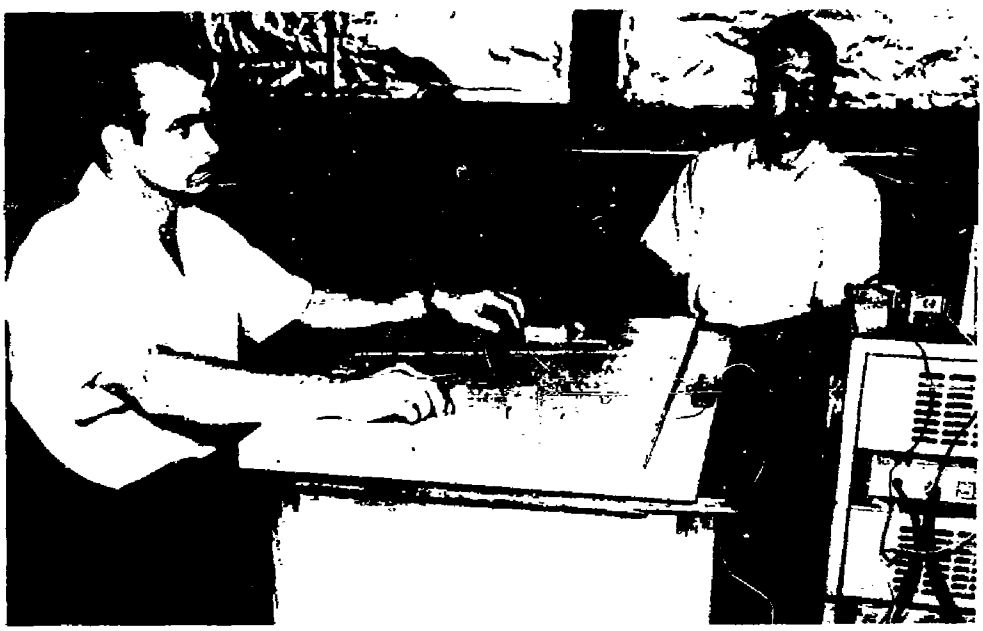

Figure 4. Simultaneous Response Study Apparatus: Subject at Response Panel and Experimenter

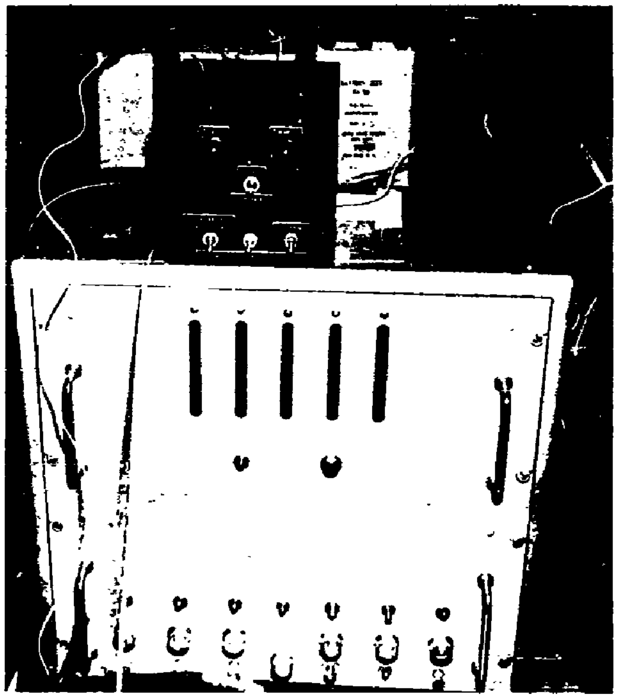

Figure 5. Simultaneous Response Study Apparatus: Close-up of Interval Timer and Control Unit

In operation, the release of either the right- or left-hand key on the subject's response panel started the interval timer and the release of the alternate key stopped the timer. The neon bulbs on the control box identified for the experimenter which key was released first.

The response panel was a 78- by 50-cm gray board mounted horizontally on a table 77 cm high. The two response keys were mounted 46 cm apart, 24 cm from the near edge of the board. The 46-cm separation of the keys approximates the shoulder width of USAF flying personnel.

The keys were simple, normally open leaf springs. Each key required approximately 30 grams, at its near end, to depress and make contact. In the open position the near edge of the key was approximately 4 cm above the panel and in the closed position 1 cm above the panel. These characteristics are not considered critical. There was no noticeable change in the tension and travel of the keys during the course of the experiment. Nevertheless, they were occasionally interchanged.

The control box housed 2 neon bulbs, 2 millisecond relays, and a number of calibration switches. A circuit diagram is shown in figure 6.

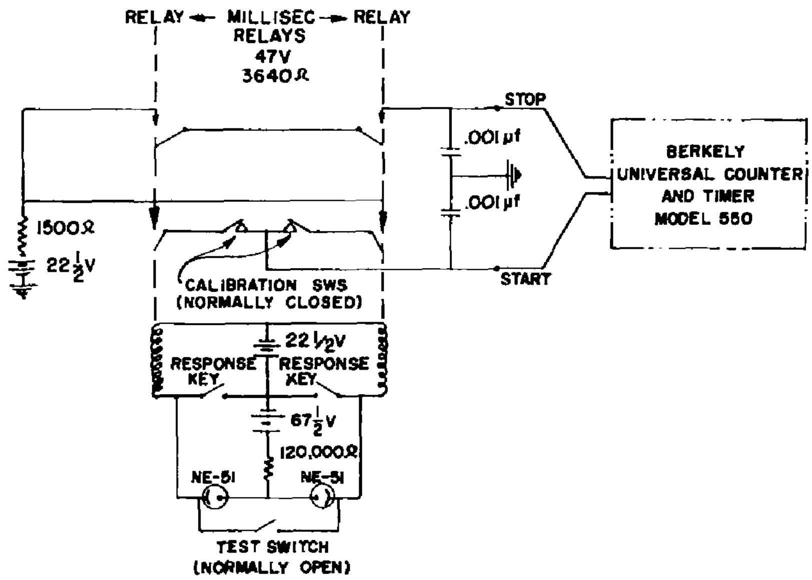

Figure 6. Circuit Diagram for Simultaneous Response Study Apparatus

The neon bulbs on the experimenter's panel indicated which key the subject released first. If, for example, the subject released the left response key first only the left bulb lit. The bulb remained lit until the subject again depressed both response keys preparatory to the next trial.

The two millisecond relays in the control box were actuated by the release of the corresponding response key. The relays, in turn, started and stopped the timer. Had the relays been perfect or perfectly matched there would be no error in timing. However, the relays were not perfectly matched (although nearly so). The two armatures of a single relay were not perfectly synchronized with each other nor with the corresponding armatures of the alternate relay. The maximum error was, however, very small: less than 0.1 msec (millisecond).

The calibration switches on the control panel permitted accurate determination of the timing error. If the left key was released first the timed interval was 0.03 to 0.04 msec too large; if the right key was released first the timed interval was 0.05 to 0.08 msec too large. The timing error was checked before and after each experimental session and remained within these limits throughout the course of the experiment.

Since the timing error was so small no attempt was made to correct the scores. However, any recorded score less than 0.1 msec was discarded—primarily because the neon bulbs indicating which key was released first were also unreliable at these very short intervals. Fortunately, there were very few scores within this range of ambiguity.

The timer was a standard Berkley model 550 counter-timer reading to 9999.99 msec. The counter was calibrated against a 60-cycle input and was accurate and reliable and remained so throughout the experiment.

During the test a few unusually long intervals were recorded. In these cases, line voltage transients or radiation from unknown sources may have started the counter prematurely. These unusually large time scores were also discarded.

Subjects and Procedures

Twenty subjects, 3 female and 17 male, were recruited from office personnel. Sixteen subjects were less than 30 years old; the oldest of the group was 43. Two of the subjects were left-handed. All subjects disclaimed any manual anomalies.

Standardized explanations and instructions were read to each subject. The instructions emphasized using the index fingers for depressing and releasing the response keys.

Each subject received 10 practice trials followed by two 30-trial test sessions separated by a 5-minute break. The subjects were given the results for each of the 10 practice trials. They were not provided results during the test sessions.

At the beginning of each group of 30 trials, a "ready" signal was given. The subject could release the keys any time he was ready after the signal. The "click" of the interval timer resetting itself approximately 30 seconds after each trial took the place of the ready signal for the remaining 29 trials. The trials were thus self-paced within the restraint of the 30-second timer interval following each trial.

RESULTS

Sixty test trials were administered to each of the 20 subjects. Of the 1200 obtained scores 5 were considered anomalous and were discarded. Probable causes of these anomalous scores and the justification for discarding them are described in the preceding apparatus section. The means and standard deviations of each subject's array of scores is given in table I following.

TABLE I

INTERVAL BETWEEN RELEASE OF KEYS
(in milliseconds)

Subject	Mean	S. D.
1	+ 0. 94	12. 40
2	- 0. 32	12. 24
3	+ 4. 48	6. 95
4	+ 0. 11	10. 89
5	-12. 88	17. 82
6	- 3. 08	12. 88
7	+ 7. 34	9. 11
8	+ 2. 43	7. 26
9	+ 1. 72	13. 81
10	-11. 45	13. 89
11	+ 1. 65	11. 91
12	+ 8. 77	10. 67
13	- 2. 49	10. 56
14	+ 5. 86	10. 50
15	- 0. 79	9. 74
16	+ 0. 62	9. 43
17	+ 3. 05	10. 14
18	- 7. 79	14. 86
19	- 0. 63	5. 86
20	+ 4. 20	11. 04

The standard deviation of the individual subject's means is 5.48 msec. The mean of the individual standard deviations is 11.10 msec.

The mean of all 1195 scores was +0.087 msec (+ indicating the right-hand key released first). The standard deviation was 11.45 msec.

The distribution of scores was compared, by class intervals of 5 msec, with a theoretical normal distribution having a mean of zero and a standard deviation of 11.45 msec (see figure 7). A Kolmogorov-Smirnov "one-sample" statistical test revealed that the difference between the theoretical and obtained distributions was not statistically significant ($p = 0.20$).

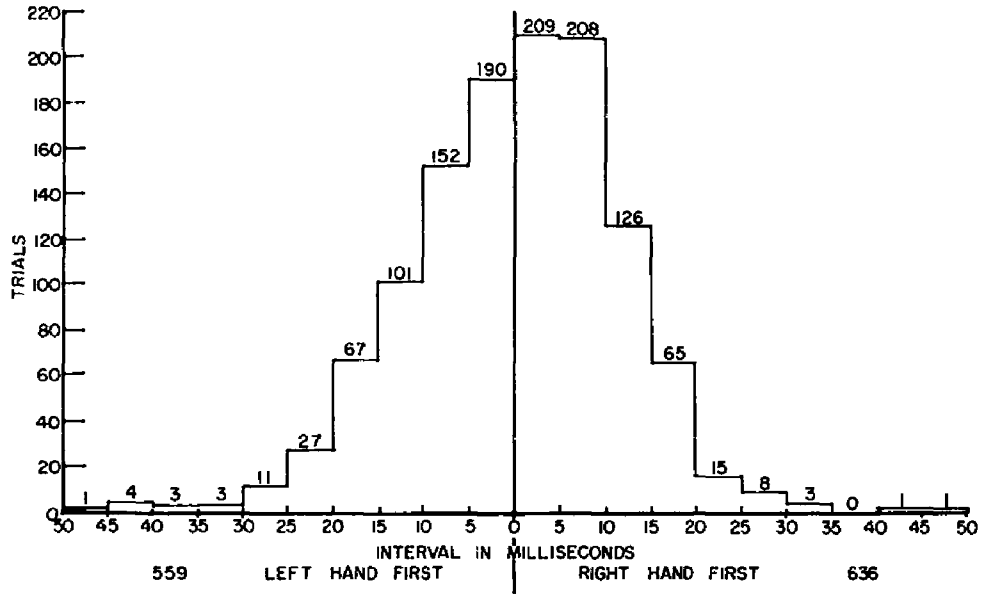

Figure 7. Frequency Distribution: Interval Between Responses

Of the 1195 scores, 63.5 percent were in the range of -10 to +10 msec; 93.6 percent were within ±20 msec. Assuming a normal distribution as above (mean = 0; σ = 11.45 msec), 50 percent of the scores would be expected to fall within ±7.7 msec of exactly simultaneous, 75 percent within ±13.2 msec, 95 percent within ±22.4 msec, and 99 percent within ±29.6 msec.

In 636 (53 percent) of the 1195 trials the right-hand key was released first and in 559 (47 percent) of the trials the left-hand key was released first. Although statistically significant ($p = .03$), this slight preponderance of right-hand first responses would not appear to be of practical consequence.

Subjects 1 and 12 stated that they were left-handed. However, their performance scores are not conspicuously different from those of the 18 right-handed subjects (see table I).

Subjects 2, 11, and 20 were female. Their performance scores are not conspicuously different from those of the 17 male subjects (see table I).

The distribution of all scores for the first 25 trials was compared with the distribution of all scores for the last 25 trials (figure 8). A Kolmogorov-Smirnov "two-sample" statistical test reveals that the difference between the two distributions is not statistically significant (p = 0.15). The mean and standard deviation of each subject's scores over the first and over the last 25 trials is presented in table II.

TABLE II

INTERVAL BETWEEN RELEASE OF KEYS
(in milliseconds)

	First 25 Scores		Last 25 Scores	
Subject	Mean	S. D.	Mean	S. D.
1	-2.87	12.18	6.41	13.86
2	-5.30	12.06	2.38	12.13
3	5.08	7.90	4.61	6.95
4	-2.02	10.16	2.75	10.81
5	-13.10	16.82	-12.64	17.60
6	-8.63	13.33	1.50	14.08
7	6.63	8.97	8.16	9.15
8	-0.86	6.84	5.13	7.90
9	-0.81	11.23	1.81	10.04
10	-11.87	13.89	-11.86	15.00
11	6.40	9.75	-3.76	12.34
12	9.69	11.07	11.37	11.49
13	-0.97	8.52	-5.27	13.40
14	2.95	9.26	6.02	11.30
15	0.40	9.02	-4.02	11.25
16	-0.60	9.67	2.52	9.62
17	5.15	10.86	0.28	9.77
18	-1.04	7.87	-15.03	20.30
19	-1.23	5.22	-0.35	5.60
20	2.57	9.70	7.66	12.76

The standard deviations of the scores of 17 of the subjects were larger for the last 25 trials than for the first 25 trials. The variability (standard deviation) of the first 25 trials was compared, using the Wilcoxin matched-pair signed rank test, with that of the last 25 trials. The mean difference between the variability of the first and last 25 trials was statistically significant (p = .05).

In the first 25 trials 49.6 percent of all responses were right hand first. In the last 25 trials 55.6 percent of all responses were right hand first. In the latter case (55.6 percent), the excess of right-hand-first responses is statistically significant (p = .02) but is of no apparent practical importance.

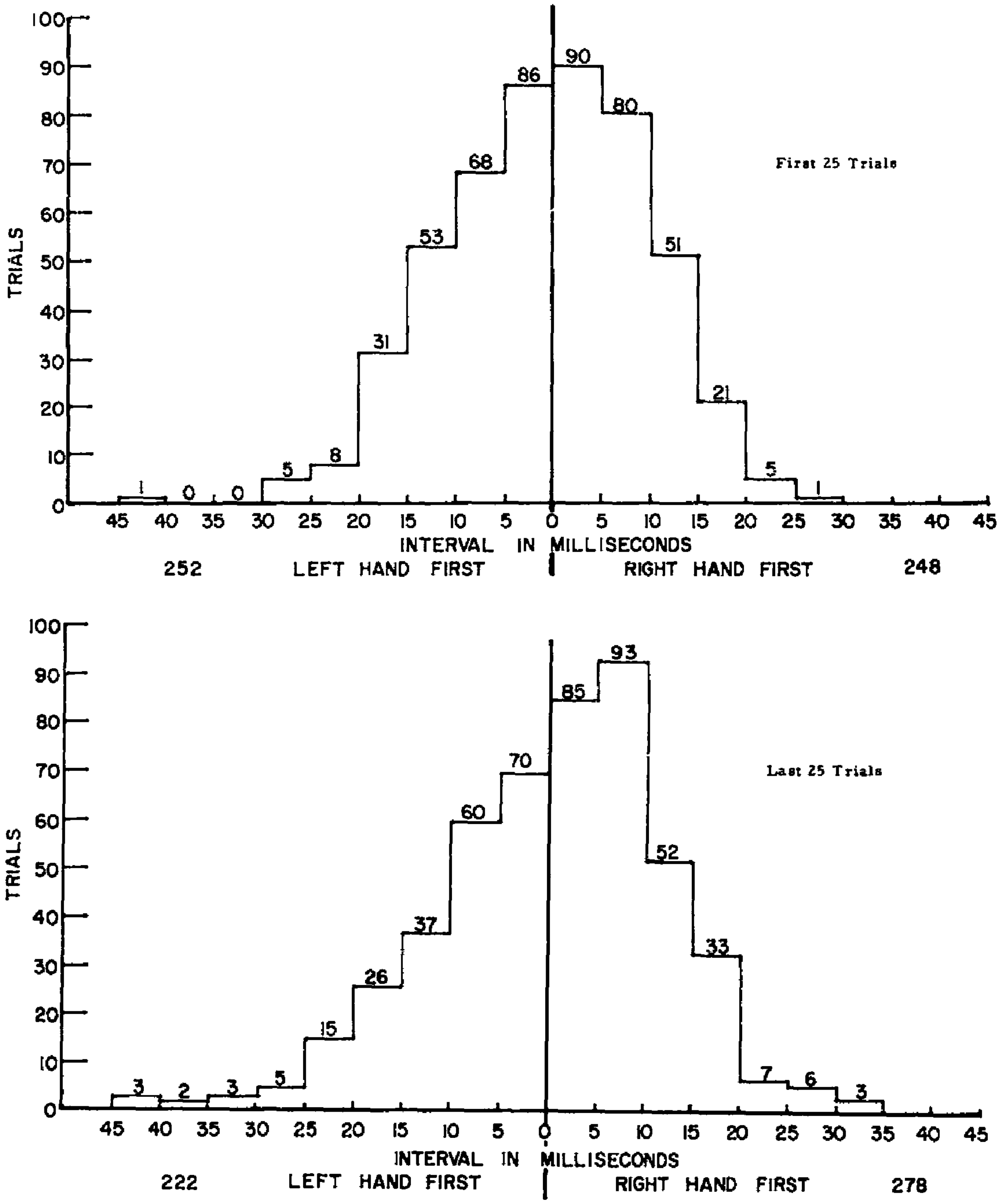

Figure 8. Frequency Distribution: Interval Between Responses, Comparison of First 25 Trials with Last 25 Trials

DISCUSSION AND CONCLUSIONS

The primary purpose of this experiment was to obtain an estimate of the limits of man's ability to execute simple control movements simultaneously with the two hands. The subjects were comfortable, unencumbered, and unrestrained. Only the very simple response of releasing two spring-loaded key-switches was required. The reason for requiring the subject to release rather than to depress the keys was to minimize the variability that might otherwise accrue due to bilateral differences in the distance, velocity, or accuracy of the response movement itself. It is doubtful (but not demonstrated) that any practical switch-response combination would result in better, more accurate, or less variable performance than that obtained.

The results indicate that the over-all, average, temporal interval between bilateral responses, when the subjects attempted to execute the responses exactly simultaneously, is very close to zero. However, the variability of the temporal interval is relatively large. The standard deviation of the distribution of all responses is 11.45 msec. Approximately 94 percent of all responses fell within the 40-msec range—left hand first 20 msec, right hand first 20 msec.

The average temporal interval between response pairs of 6 of the 20 subjects was less than 1 msec; the average temporal interval of 6 other subjects exceeded 5 msec. The intra-subject standard deviations of the temporal interval between response pairs was fairly constant. For 16 of the 20 subjects the standard deviation lay between 6 and 14 msec; the average of the intra-subject standard deviation was 11.10 msec.

The data reveal that the subjects did not consistently synchronize their bilateral, simultaneous responses. For our illustrative man in space using bilateral reaction controls, linear translation without rotation would be the exception rather than the rule.

This conclusion must, however, be tempered by the possibility that performance might be appreciably improved with practice, knowledge of results, or a combination thereof. Although these possibilities should be investigated further the current evidence is not encouraging. Two bits of evidence argue against the possibility.

In the basic experiment described herein, performance variability generally increased rather than decreased from the first 25 to the last 25 trials. The subjects may have fatigued, but the task was self-paced and there was an interpolated 5-minute rest interval.

Lack of knowledge of results might explain the apparent degradation, rather than improvement, in performance with practice. To examine this hypothesis, two subjects (not used in the experiment proper) were each given 400 trials spread over 4 days, 25 trials per session, 4 sessions per day. For these subjects, the timer and the control panel with its two lights indicating which hand was withdrawn first were placed within the subject's view directly behind the response keys. Thus, the subject had immediate knowledge of his prior response. In addition, the subject wore headphones that presented a loud click to the left ear when the left key opened first, a loud click to the right ear when the right key opened first, and a very faint click to both ears when the keys opened simultaneously.

Over the 4 days of testing, the subjects' performance improved but only slightly and irregularly. The mean of subject A's scores decreased from 4.96 msec the first day to 1.39 msec the fourth day. His standard deviation decreased from 20.31 msec to 12.15 msec over the same period. Subject B's mean scores decreased from -5.34 to -1.72 msec and his standard deviation from 9.39 to 8.36 msec. On the basis of these two subjects, practice with knowledge of results does not appear to be effective.

In many, if not most, control systems the control must be both activated and deactivated. Errors in synchronizing the activation and deactivation of the control pair might tend to cancel. This is true, however, only if the activation-deactivation response errors are correlated. If the errors are independent and random, as is believed to be the case in this experiment, the variability of the total activation-deactivation cycle is actually larger than the variability of either the activation or deactivation errors. Assuming the standard deviation of activation errors and of deactivation errors both to be 11.45, the variability of complete on-off cycles would be expected to be $\sqrt{2} \times 11.45$ or 16.2 msec. Only if the coefficient of correlation (r) between activation and deactivation errors were between -1.0 and -0.5 (which appears most unlikely) would the variability be decreased.

On the basis of the evidence obtained, it would appear unwise to expect man to perfectly synchronize his bilateral responses. Even under what would appear to be the simplest possible situation, errors up to 20 msec would be expected about 95 percent of the time. In a real situation in which more complicated controls are used and the operator is encumbered and restrained, the variability of the errors of synchronizing would probably be considerably, perhaps 2 or 3 times, greater.

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report, Jan 63, iii + 11 pp. incl. illus., tables.
Unclassified report

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